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Conservation in Canada and beyond:
Developing a replicable place-based systematic approach.
Research Paper
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Abstract

Biodiversity is in decline worldwide. Protected and conserved areas are an effective measure to protect species and halt the loss of habitat. With human activities spreading into the last remaining wilderness, a placed-based approach aimed at conserving natural habitats appears as a solution. My study aims at creating a replicable framework towards a place-based systematic approach for conservation. My study includes data publically available on different biodiversity proxies identified through a literature review. I selected six proxies accounting for ecological representation, road fragmentation, size of the area, distance to existing protected areas, number of species at risk, and mean evapotranspiration. Areas of potential for protection were found in all five ecozones selected for analysis. A Spearman nonparametric correlation test linked conservation potential to the number of species at risk and distance to other protected areas. The model suggests important gains could be made by increasing the size of existing protected areas. Findings indicate that this place-based approach might not be appropriate for conservation in southern Canada. Even though areas of interest for protection are found, proxies poorly adjusted to localized threats decrease the model's applicability. Knowledge gaps were identified around harmonizing biodiversity threats, species at risk triage and protected areas in Canada and worldwide.

Keywords: conservation, place-based conservation, systematic conservation approach, Canada.

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Introduction

Anthropogenic disturbances in natural habitats are rising. Ecosystem services are increasingly impacted by resource exploitation. Biodiversity is rapidly disappearing and scientists now suggest we entered the sixth mass extinction event in earth's history (Barnosky et al., 2011). Habitat conservation is proven to mitigate the impacts of habitat and ecosystem services loss (Margules & Pressey, 2000). Protecting biodiversity and ecosystem services, in turn, mitigates the long-term effects of climate change and land use change (Jantz, Goetz, & Laporte, 2014).

It is of high importance to create protected areas (PA) where conservation potential exists. The IUCN defines protected areas as: "clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values"(IUCN, 2008).

Barriers hinder the establishment of protected or conserved areas and their stewardship. Protected areas have historically been located in remote regions to minimize the effects on the local economy (Margules & Pressey, 2000; Venter et al., 2014; Wiersma & Nudds, 2009). This tendency led to species found outside of protected areas to be highly impacted by human activities. As habitats shrink, so does population sizes and genetic diversity. The recovery of species requires important economic and ecological resources. Recovery is challenging and an ever-increasing number of species go extinct (Gerber, 2016; Martin et al., 2018; Schneider, Hauer, Adamowicz, & Boutin, 2010).

Rapid degradation of global biodiversity pressed conservationist to study ways to increase biodiversity conservation outcomes. Systematic conversation frameworks have been proposed as a solution (Margules & Pressey, 2000). Such frameworks optimize resources by focusing on areas with conservation potential (Albert, Rayfield, Dumitru, & Gonzalez, 2017; Coristine et al., 2018; Nicholson & Possingham, 2006; Schwenk & Donovan, 2011).

A new approach is needed to ensure Canada's biodiversity is conserved. The important diversity of ecosystems found in Canada complicates defining areas worth concentrating conservation efforts.

My objective is to create a systematic place-based conservation framework unique to the Canadian context. The conservation portrait of Canada shows SAR recovery is difficult, connectivity between PA is poorly understood, and no national key biodiversity areas standards exist (Chamberlain, Rutherford, & Gibeau, 2012; Coristine et al., 2018; Dearden & Dempsey, 2004; Deguise & Kerr, 2006; Wiersma & Nudds, 2009). Flagship species with debatable chances of recovery (e.g. Woodland Caribou) monopolize federal funding leaving little protection for others (Boutin et al., 2012; Hauer, Adamowicz, & Boutin, 2018; McLoughlin, Dzus, Wynes, & Boutin, 2003; Serrouya & Wittmer, 2010).

Building on the IUCN definition of a protected area and on a literature review of place-based conservation, my study creates a GIS model supporting the creation of new protected areas in Canada. The model proxies are based on scientific literature to represent regional variations. Proxies are meant to be holistic and to account for a variety of metrics. This exercise builds on already existing metrics, such as species at risk (SAR) critical habitat (CH), evapotranspiration (ETP), and ecological representation. Areas assumed to be worthy of further review are spatially identified. This project is unique in a way that it aims at creating a replicable framework able to target spatially defined areas deemed worthy of legal protection.

Literature review

Selection criteria are based on scientific literature for placed-based conservation measures and broader conservation frameworks. Word searches on JSTOR, SCOPUS and Web of Science databases were conducted with the following keywords: **Place-based conservation*, **Species at risk conservation*, **conservation triage*, **connectivity*, **fragmentation.* Articles are selected based on geographical and biological similarities to Canada (e.g. ungulate study in mountainous habitats) or on similar human footprints (e.g. extensive road network). Results range from early 1990 to 2018 (45% of articles published in the last 10 years). Selected proxies are based on most often cited values for conservation: ecosystem condition, level of threats, and species richness.

Finding potential sites

Many studies now point towards a triaged approach targeting SAR with realistic chances of recovery for inclusion in conservation frameworks (Gerber, 2016; Martin et al., 2018; Schneider et al., 2010). My study ranking builds upon Gerber (2016) argument that resources should not always be consistent with species threat level.

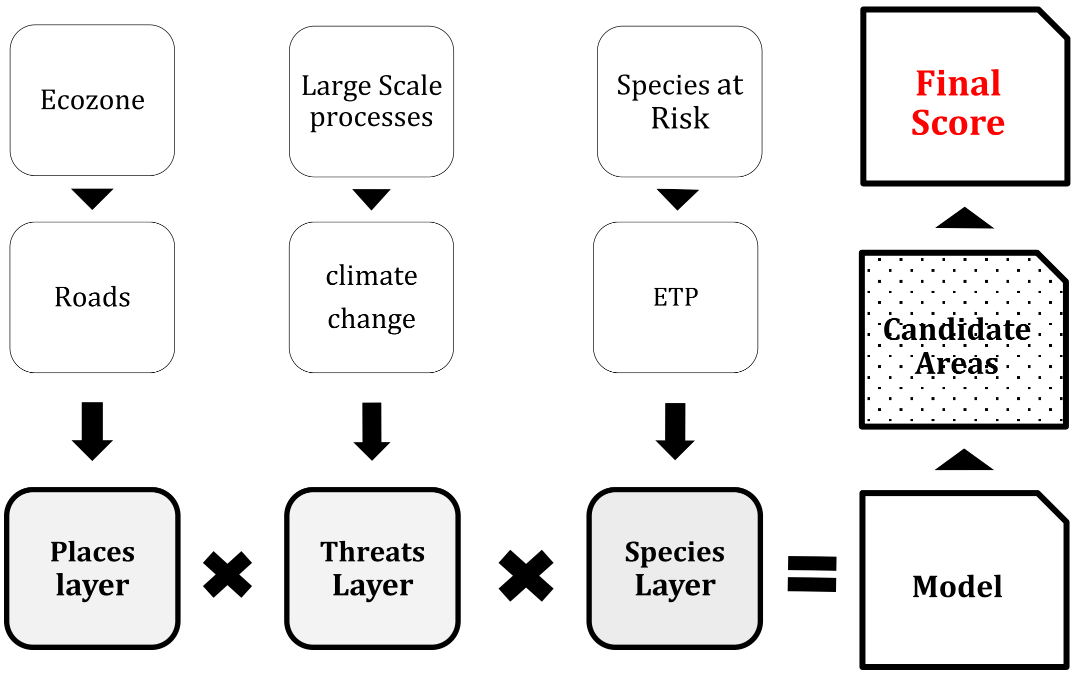
Weight is unevenly distributed within the six proxies chosen. Building on place-based and triage approach to SAR, physical characteristics of potential sites receive the strongest weight. Studied ecozones differ greatly in biodiversity potential and habitat characteristics. All proxies scoring represent regional variation to include areas worth protecting in low productivity ecozones with poor relative protection. Final scores could poorly correlate with high biodiversity hotspots in Canada due to scoring. Areas might satisfy the model's criteria at the ecozone scale but have reduced pertinence on a national scale.

Final Score

Each candidate area is given a *final score* computed from places, threats and species layers (figure 1). Highest scoring areas classify as high potential for protected area designation.

Data are collected from official sources (see table 1) with particular efforts to choose recently updated information. The three types of layers are merged together in the model to identify candidate areas for protection (Figure 1). Places proxy have the ability to disqualify sites. Proxies for the threats and species layer are scored above zero so they may not disqualify a site on their own. Threats and species are meant to orient the model but may not exclude an area. Each information layer is projected into *Albers Equal Area Conic* to lower the possibility of spatial distortion (ESRI, 2018).

Figure 1: Model visualization



Proxies and Scoring

Table 1: Selection criteria table

Criteria	Proxy	Source
PLACES		
➢ Ecological representation	Canada Ecozone	(CCEA, 2016)
➢ Fragmentation	Canadian Road Network (CRN)	(N. R. Canada, 2015)
THREATS		
➢ Climate change	Canadian Protected Conserved Areas Database (CPCAD)	(E. and C.C. Canada, 2018)
➢ Large-scale processes	Candidate area size	(Gurd, Nudds, & Rivard, 2001)
SPECIES		
➢ Species at risk	SARA critical habitat (CH)	(E. and C. C. Canada, 2018)
➢ Evapotranspiration	Average Evapotranspiration by drainage basin	(Statistics Canada, 2017)

Places

Ecological representation

The 18 Canadian *Ecozones* represent ecological assemblages with similar mosaics of plants, wildlife, climate, landform, water, and human activities (CCEA, 2016). The Ecozones cover the entirety of Canada and are created from Environment and Climate Change Canada (ECCC) and Agriculture and Agri-Food Canada (AAFC) data. Ecozones were updated in 2014 and represent the latest available information on ecological assemblage in Canada. The Ecozone layer is selected for its peer-reviewed methodology and its national recognition.

Table 2: Least represented Ecozone and scoring (E. and C. C. Canada, 2016)

Ecozone	Proportion of Area Protected (%)	Scoring
Mixedwood Plains	1,9	1
Atlantic Highland	4,1	1
Prairies	5,9	1
Taiga Shield	8,4	1
Northern Arctic	7,1	1
Other Ecozones	>8,4	0

Number of Categories:

There are two possible categories for this proxy. The five least proportionally protected ecozones in Canada are chosen given the limited amount of time and resources available to complete this study's objective. The other 13 ecozones fall outside the scope are not considered.

Variable weights:

Ecozones either receive a score of 1 or 0 to either ensure consideration or disqualification of the area. The final model only considers ecozones scored 1.

Consideration in the final model:

All possible scoring for this proxy is between 1 and 0. The ecozone proxy is one of the only two (ecozone & fragmentation) that have the power to completely disqualify areas from the final model.

Limitations:

Because the ecozone ecological representation framework follows similar mosaics of habitats, some rare or unique types of areas with high conservation potential might not be considered (rare habitats, climate refugia, etc.).

Fragmentation

Studies show that road fragmentation has negative effects on species movement, population health, genetic diversity, and climate-driven migration (Lesbarrères & Fahrig, 2012; Lesmerises, Dussault, & St-Laurent, 2012; Madadi et al., 2017; Rivera - Ortíz, Aguilar, Arizmendi, Quesada, & Oyama, 2015; Trombulak & Frissell, 2000). Shannon et al. (2016) find roads to have additional effects on habitat-use by noise levels. Building on these results, Madadi et al. (2017) finds that engine noise has negative effects on species occurrence 50 m to 2000 m nearby roads.

Table 3: Fragmentation scoring for candidate areas

Distance from roads (m)	Score
> 2000	1
< 2000	0

Number of Categories:

There are two possible categories for this proxy. Areas less than 2000 m from roads are disqualified consistently with findings on collision and engine noise impacts. This proxy disqualifies heavily urbanized areas where conservation potential is low or very expensive.

Variable weights:

Areas either receive a score of 0 or 1 to ensure zones close to roads are disqualified. Areas found outside of the buffer are considered for protection.

Consideration in the final model:

The fragmentation proxy is one of the only two (ecozone & fragmentation) that has the power to completely disqualify areas from the final model.

Limitations:

Differently trafficked roads have distinct effects on populations. This proxy applies the same buffer to all the roads in the Canadian Road Network. Classifying the data for different sizes of buffers would ensure that highways are rated has higher-impact than small seasonal roads.

Threats

Climate Change

Populations migration is thought to increase resilience to climate change through genetic diversity (Albert et al., 2017; Hampe & Petit, 2005; Rivera-Ortíz et al., 2015; Wiersma & Nudds, 2009). Ecosystem migration rate(i.e. boreal forest) is treated as a proxy for resilience to climate change. Studies found North American forests are expected to migrate 10 km north each decade (Aitken, Yeaman, Holliday, Wang, & Curtis-McLane, 2008; Iverson, Schwartz, & Prasad, 2004; Malcolm, Markham, Neilson, & Garaci, 2002). Potential movement of ecosystems and forest assemblage (i.e. habitat) due to climate change could impact many Canadian species.

Figure 2: Northward climate migration

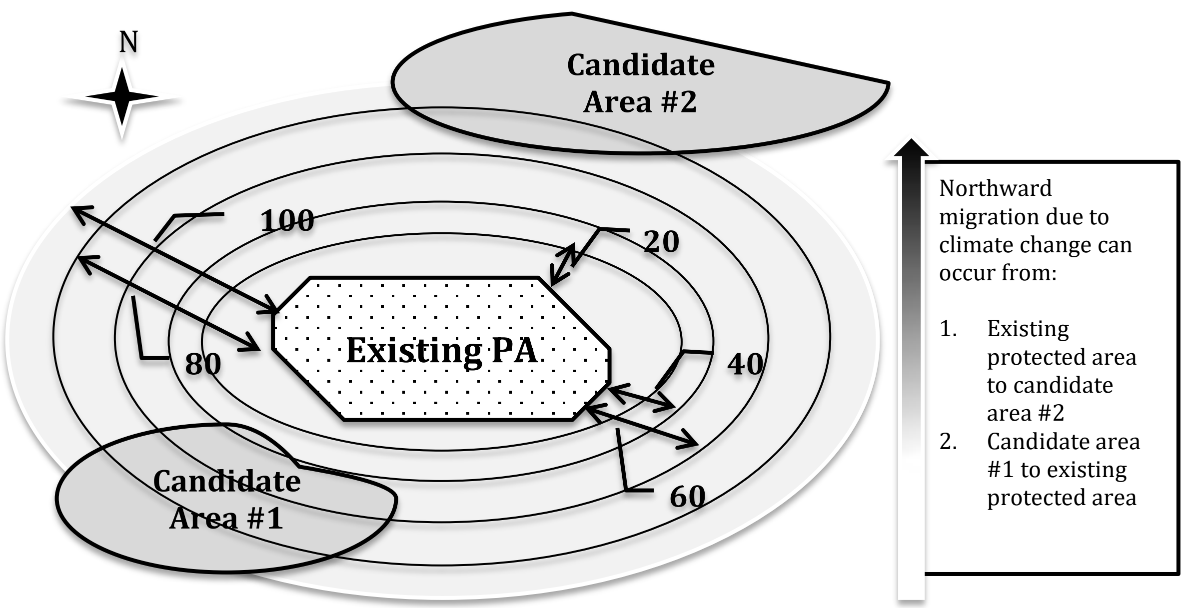


Table 4: Migration scoring for candidate areas

Distance from existing protected areas (km)	Score
≤ 20	1
> 21 ≤ 40	0.9
>41 ≤ 60	0.7
> 61 ≤ 80	0.3
> 81 ≤ 100	0.2
>100	0.1

Number of Categories:

There are six categories for this proxy. Each rank represents a 20-year migration period. The planning period is based on a GCM model with a 100 year prediction period (Iverson, Schwartz, & Prasad, 2004). Iverson et al. (2004) calculate successful migration rates for jumps of 10 km north. To limit categories, 20 km ranks are chosen. Categories are based on the chances of successful colonization for each migratory jump of 20 km. Iverson et al. (2004) proved that even though migrations can occur over 100 km north of the base population, colonization success decreases rapidly.

Variable weights:

Scoring for all ranks is consistent with the chances of successful migration. Given species different vagility and migration rate, closer candidate areas have higher migration potential. The closest area receives a scoring of 1 and other categories score follows the decrease in colonization success. Declines in success rate ranged from 50% (-0.1), 150% (-0.2), and 200% (-0.3). Areas more than 100 km away from existing PA will receive the lowest possible score.

Consideration in the final model:

All possible scoring for this proxy is between 1 and 0. The first category is scored with a 1 and other categories are scored over 0 because this proxy may not disqualify a site on its own.

Limitations:

Lower resolution in the model due to the scoring being adapted from a 10 km in Iverson et al. (2004) to a 20 km scale. Rate of successful colonization has also been adapted to new intervals. The proxy does not account for species-specific migration. This proxy could leave out some species with low vagility.

Large-Scale processes

Disturbance cycles and ecological succession affect large areas and promote habitat diversity (Hobbs & Huenneke, 1992). Large areas have increased biodiversity due to their likeliness to encompass rare ecosystem types (e.g. Old Growth forests). Large mammals require large areas to live and reproduce. Black and brown bears, often used as umbrella species, have home ranges of 150 km^2 to 900 km^2 (Noss, Quigley, Hornocker, Merrill, & Paquet, 1996). Wolves and Wolverine require between 400 km^2 and 2 000 km^2 for pack territories (Ibid, 1996). Minimum reserve area for North American large mammals has been found to be between 2 700 km^2 and 13 000 km^2 (Gurd et al., 2001).

Table 5: Size scoring for candidate areas

Size of candidate areas (km^2)	Score
> 13 300	1
> 5 030 ≤ 13 300	0.4
> 2 700 ≤ 5 030	0.3
≤ 2 700	0.2

Number of Categories:

There are four possible ranks for this proxy. The categories are based on Noss et al. (1996) conclusion as to minimum reserve area for population sustainability. The study found that areas of less than 2 700 km^2 usually need human management to avoid loss of species. Areas of 5 030 km^2 and more conserve the historical assemblage of mammals. Larger carnivores, such as grizzly bears, gray wolves, and wolverines require an area of 13 300 km^2 to have zero risks of extinction from population collapse.

Variable weights:

Areas bigger than the requirement described in Noss et al. (1996) receive a score of 1. Other categories are scored according to their mean size (9 165 km^2 mean for 5 030 km^2-13 300 km^2 category). This distribution of weight is also consistent with the rapid loss of ecological processes between categories. Reserves meeting Noss et al. (1996) optimal size have the highest possible score.

Consideration in the final model:

All possible scoring for this proxy is between 1 and 0. The first category is scored as 1 while other categories are scored over 0 because this proxy may not disqualify a site on its own.

Limitations:

The relatively low number of categories accounts mostly for species population sustainability and not for large scale processes such as fire cycles. Other large-scale processes leading to ecological succession occurring on different spatial scales are not taken into account by the model.

Species

Species at Risk

Critical habitat for species at risk is included in the model to ensure disappearing biodiversity is protected and recovered. Critical habitat is defined as habitat "that is necessary for the survival or recovery of a listed wildlife species" (E. and C. C. Canada, 2002). Critical habitat is delineated within each species area of occurrence. SAR score is based on the percentage of total critical habitat within each ecozone (Table 6). Most of the limited-range SAR with critical habitat in heavily fragmented landscapes could be excluded from the final. In such cases, alternative protection measures exist (e.g. Sec. 11 conservation agreements under SARA, economic incentives for private landowners to protect SAR habitat.). Areas where critical habitat concentrate receives higher value increasing their *final score*.

Table 6: Species at Risk scoring for candidate areas

Species at Risk (% of total CH)	Score
100	0.5
≥ 75 ≤ 99	0.4
≥ 50 ≤ 74	0.3
≥ 25 ≤ 49	0.2
≤ 24	0.1

Number of Categories:

There are five possible categories for this proxy. Species at risk with critical habitat identified (116) are widely distributed. Percentage of total critical habitat by ecozones better illustrates local variations. Areas with the highest number of SAR (100% of total SAR CH) receive the highest scoring. This proxy scoring was divided into five categories of 25% ranks to capture the regional variation in national species at risk number. This arbitrary decision is to represent trends instead of quantitative variations between categories. This choice creates many categories to allow for the scoring to capture regional variation in SAR numbers.

Variable weights:

The first category is scored with a 0.5. Other categories are scored down by 0.1 points for each 25% decrease in category range. This scoring considers the relationship between categories and score to be linear. This proxy only captures trends in the number of CH habitats found within each ecozone. The lack of information on the quantitative benefits of CH protection prevents the score from being unique to each category.

$$x = \frac{CH}{\sum_{i}^{n} CH} \times 100$$

Consideration in the final model:

All possible scoring for this proxy is between 0.5 and 0.1. This scoring builds on the stronger importance given to physical characteristics of the landscape. Discounting the scoring for SAR supports this experiment.

Limitations:

This proxy does not account for the different Species at Risk Act classification (special concern, threatened, endangered). Species at risk could have been classified based on their level of concern. Doing such would have allowed the model to find habitats that are more critical to species at risk.

Biodiversity Potential

Average evapotranspiration (m^3/m^2) by drainage basin accounts for biodiversity on a national scale. Currie (1991) argues that annual average evapotranspiration could explain 80-90% of vertebrate richness in North America. The data (Statistics Canada, 2017) are used to select the areas within each ecozone with the highest rate of evapotranspiration (ETP). Given that ecozones and drainage basin delineations are different, the overlay of the two land classifications optimizes which area should receive stronger consideration.

Table 7: Biodiversity potential scoring for candidate areas

Evapotranspiration (% of total difference)	Score
100	0.5
≥ 75 ≤ 99	0.4
≥ 50 ≤ 74	0.3
≥ 25 ≤ 49	0.2
≤ 24	0.1

Number of Categories:

There are five possible categories for this proxy. Average evapotranspiration for all drainage basin in Canada varies greatly from the Great Lakes (0.48 m^3/m^2) to the Arctic (0.11 m^3/m^2). Categories are based on the percentage of the mean total ETP difference in ecozone to account for the wide possibility of evapotranspiration values within the study area. The first category ensures that zones with the highest evapotranspiration (100% of total ETP) in each ecozone receives the highest scoring. Four other categories are created by a steady 25% decrease with corresponding 0.1 value drop for the scoring. The division into five categories of 25% ranks captures the regional variation of this national scale measure. This arbitrary decision is to represent trends instead of quantitative variations between categories. The choice of 5 categories of 25% is to allow for the scoring to capture a wider range of regional variations.

Variable weights:

The first category is scored with a 0.5 and others are scored down by 0.1 for each 25% decrease in category range. The relationship between ETP and biodiversity potential is closely related (Currie, 1999). Given that this proxy measures trends and not quantitative differences between local ETP, a steady decrease in scoring represents the loss of biodiversity.

$$x = \frac{\Delta\, ETP}{\Delta \sum_i^n ETP} \times 100$$

Consideration in the final model:

All possible scoring for this proxy is between 0.5 and 0.1. This proxy is meant to represent biodiversity potential as a whole. Given the low scoring attributed to SAR, including this proxy will balance the weight of biodiversity outcomes in the final model. This scoring builds on the stronger importance given to physical characteristics of the landscape. ETP and SAR lower scoring supports this experiment.

Limitations:

Evapotranspiration varies greatly geographically and seasonally. The drainage basin used by Statistic Canada covers large areas. Data on evapotranspiration by ecozone regions or ecodistric would have better represented local variation in species richness. Some drainage basin stretch across many ecozones (Assiniboine-Red drainage basin in Alberta/Saskatchewan stretches between prairies and boreal shield).

Further Consideration

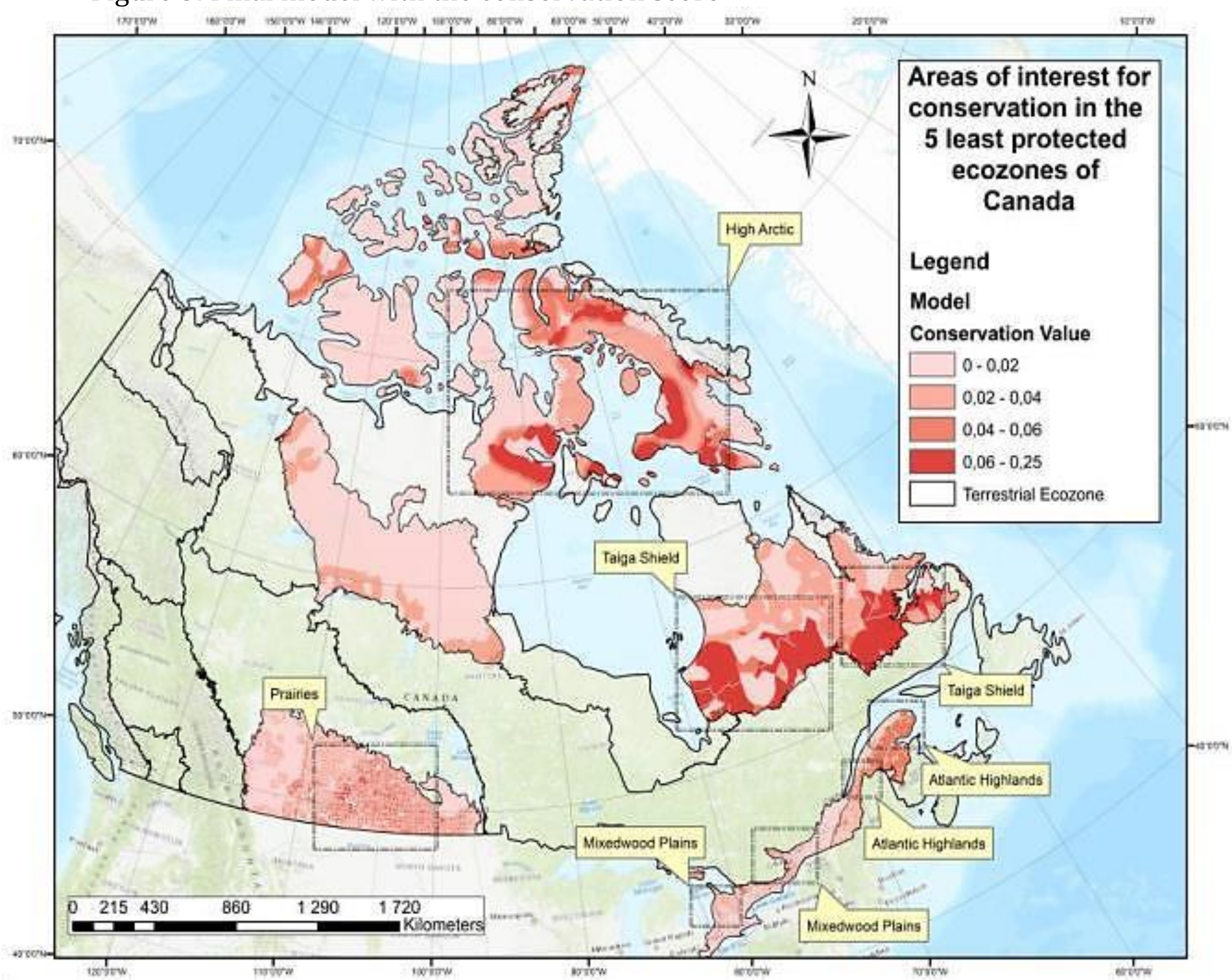
The Ecoregional assemblage layer is a more detailed ecological portrait of Canada. The former further details different habitats found in Canada. The number of Ecozones (18) is more fitted to the scope of this project and reduces the processing time it would take to work with Ecoregions (218). Using the ecozone layer limits the processing time while providing ecological assemblage peer reviewed by the Canadian Council on Ecological Areas(CCEA, 2016).

Resource extraction (e.g. oil and gas, forestry) leave important footprints on species habitat. Seismic lines negatively impact connectivity. Most of the data used in this research come from OpenData.ca or Geogratis.ca, two federally owned source for spatial data. The National Road Network is selected as being a good proxy of human footprints because of data availability.

The International Union on Conservation of Nature recently published a database on key biodiversity areas. Present Canadian KBA sites are mostly transposed IBA (Important Bird Areas) and offer no insight into the protection of other species, let alone ecosystems. A comprehensive KBA database would have been incorporated into the model.

Results

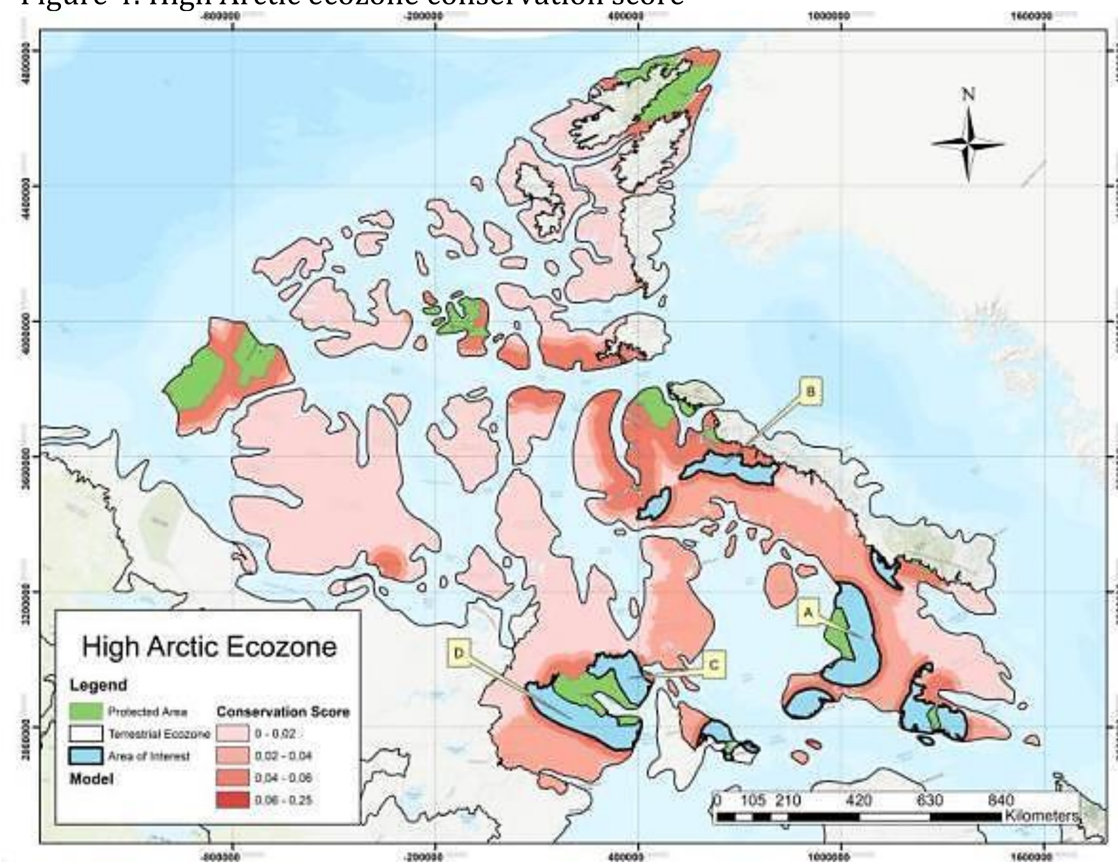
Figure 3: Final model with the conservation score



Areas of interest (AOIs) are found in all five ecozones (figure 3). Conservation values are classified based on the standard deviation of the final layer pixel value (N= 93 680 and $\bar{X}$ = 0.02). Each pixel is given a 10 km^2 area to account for the great variation between the sizes of each ecozones (116 206 km^2 to 1 481 480 km^2). Areas that have conservation values of 0.06 to 0.25 are considered as of interest for conservation as they account for the highest ranking class of areas in the studies ecozones. The model found a greater number of areas of interest in the northern and more remote ecozones ($\bar{X}$=16) while southern and more urbanized ecozones have a lower number of AOIs ($\bar{X}$=7). The average size of AOIs decreases southwards (north $\bar{X}$=11 300 km^2; south $\bar{X}$=380 km^2) where large areas are rare or inexistent. Areas with the highest final scoring are found in the taiga shield ecozone. The lowest scored AOIs are found in the prairies ecozone.

The high Arctic

Figure 4: High Arctic ecozone conservation score



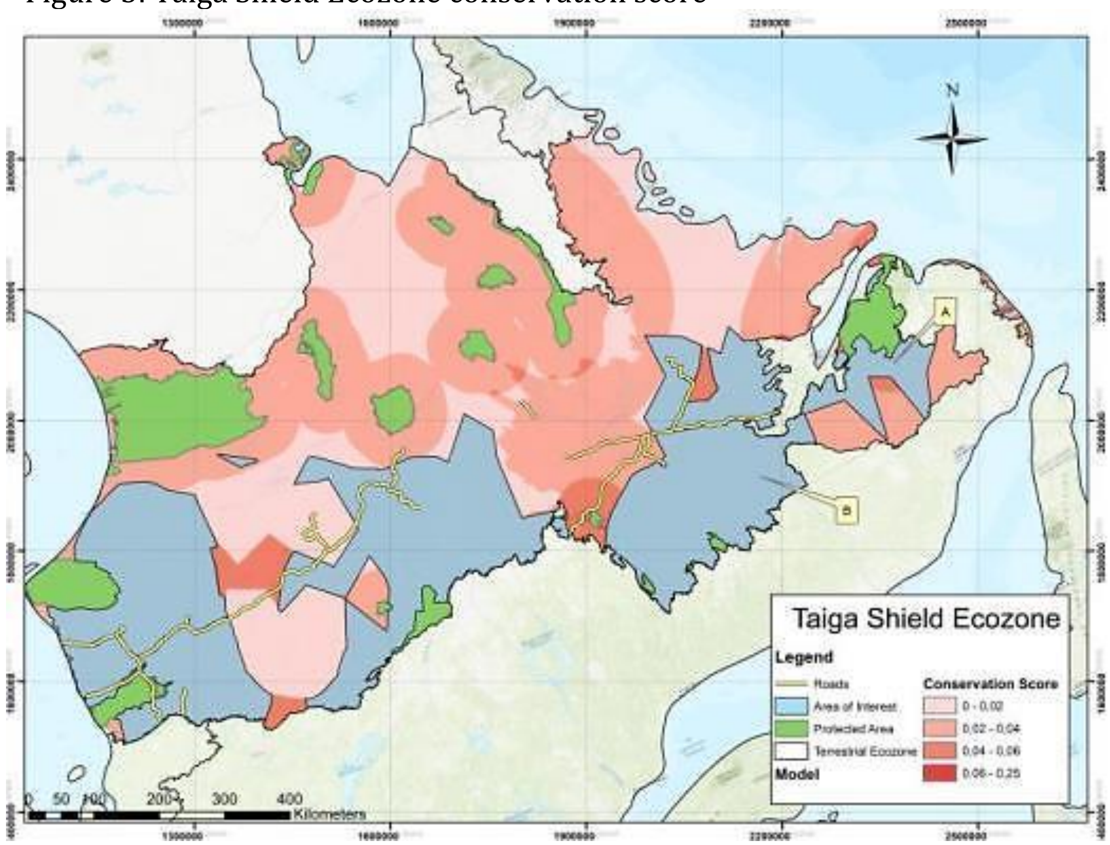
Fourteen (14) areas of interest are found in the high arctic ecozone (see in blue, figure 4). The AOIs are on the Southern Baffin Island and eastern Nunavut close to existing protected areas, within the Keewatin-Southern Baffin Island drainage basin (ETP 0.13 m^3/m^2) and have a mean size of 8 796 km^2. Mean distance to existing protected areas is 25 km and no CH is protected. AOIs are detailed (see table 8) and those with the highest final scores are identified as potential protected or conserved area and labelled from A to D on figure 4.

Table 8: Final score for high arctic AOI

Name	Size (km²)	Ecozone	Road	Migration	SAR	ETP	Area	Final
A	**28328**	**1**	**1**	**1**	**0.1**	**0.5**	**1**	**0.05**
B	**13892**	**1**	**1**	**1**	**0.1**	**0.5**	**1**	**0.05**
C	**14356**	**1**	**1**	**1**	**0.1**	**0.5**	**1**	**0.05**
D	**26838**	**1**	**1**	**1**	**0.1**	**0.5**	**1**	**0.05**
E	6702	1	1	1	0.1	0.5	0.4	0.02
F	9173	1	1	1	0.1	0.5	0.4	0.02
G	7759	1	1	1	0.1	0.5	0.4	0.02
H	4119	1	1	1	0.1	0.5	0.3	0.015
I	4420	1	1	1	0.1	0.5	0.3	0.015
J	4607	1	1	0.9	0.1	0.5	0.3	0.0135
K	522	1	1	1	0.1	0.5	0.2	0.01
L	976	1	1	1	0.1	0.5	0.2	0.01
M	663	1	1	0.9	0.1	0.5	0.2	0.009
N	789	1	1	0.3	0.1	0.5	0.2	0.003

Taiga Shield

Figure 5: Taiga Shield Ecozone conservation score



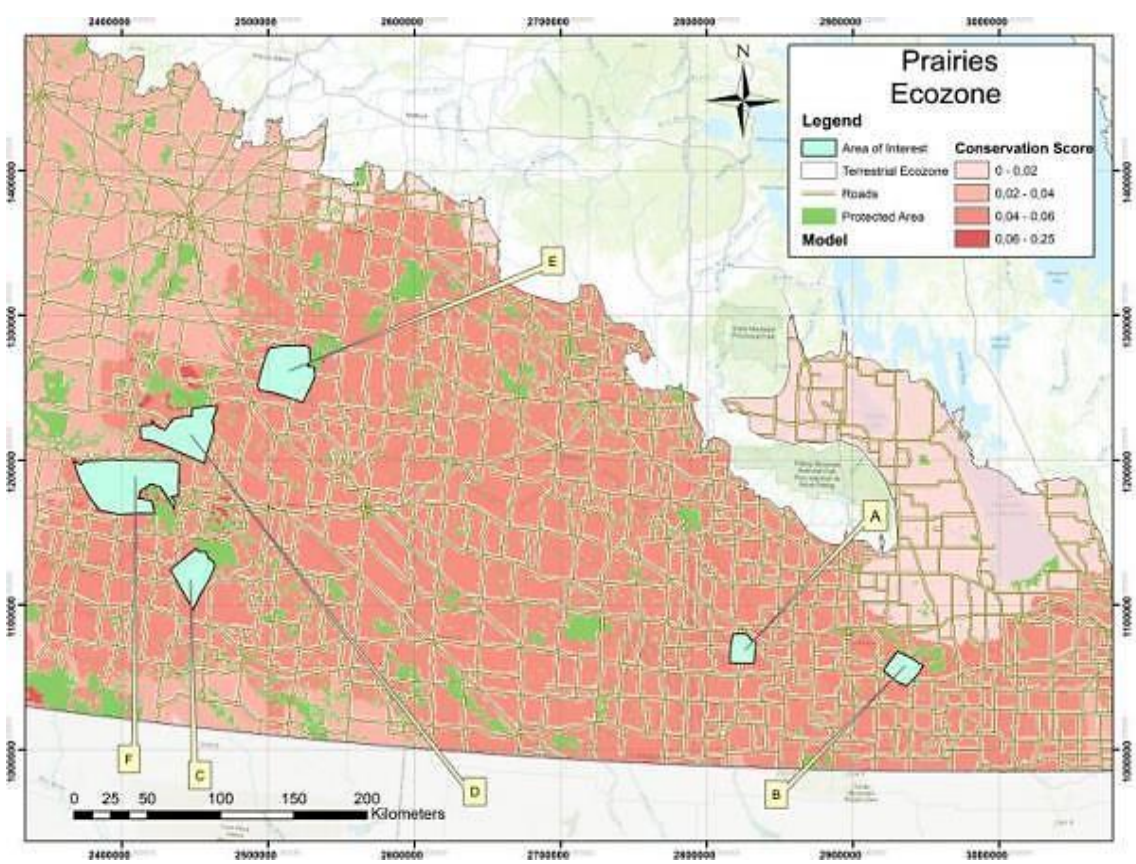
Seventeen (17) areas of interest are found in the taiga shield ecozone (see in blue, figure 5). The AOIs are found in the meridional Quebec and Southern Labrador, within boreal caribou critical habitat in the North Quebec, North Shore and Newfoundland drainage basin (ETP $\bar{X}$=0.23 m³/m²) and have a mean size of 13 819 km². Mean distance to existing protected areas is 29 km and CH is protected. All AOI are detailed (see table 9) and those with the highest final score are identified as potential protected or conserved area and labelled A &B on figure 5.

Table 9: Final score for taiga shield AOI

Name	Size (km^2)	Ecozone	Road	Migration	SAR	ETP	Area	Final
A	**51235**	**1**	**1**	**1**	**0.5**	**0.4**	**1**	**0.2**
B	**13632**	**1**	**1**	**1**	**0.5**	**0.4**	**1**	**0.2**
C	66402	1	1	1	0.5	0.2	1	0.1
D	20438	1	1	1	0.5	0.2	1	0.1
E	44243	1	1	1	0.5	0.2	1	0.1
F	12940	1	1	0.9	0.5	0.4	0.4	0.072
G	7611	1	1	0.7	0.5	0.4	0.4	0.056
H	406	1	1	1	0.5	0.4	0.2	0.04
I	364	1	1	1	0.5	0.4	0.2	0.04
J	565	1	1	1	0.5	0.4	0.2	0.04
K	6524	1	1	1	0.5	0.2	0.4	0.04
L	5460	1	1	0.9	0.5	0.2	0.4	0.036
M	375	1	1	0.7	0.5	0.4	0.2	0.028
N	517	1	1	1	0.5	0.2	0.2	0.02
O	665	1	1	1	0.5	0.2	0.2	0.02
P	2594	1	1	1	0.5	0.2	0.2	0.02
Q	953	1	1	0.7	0.5	0.2	0.2	0.014

Prairies

Figure 6: Prairies Ecozone conservation score



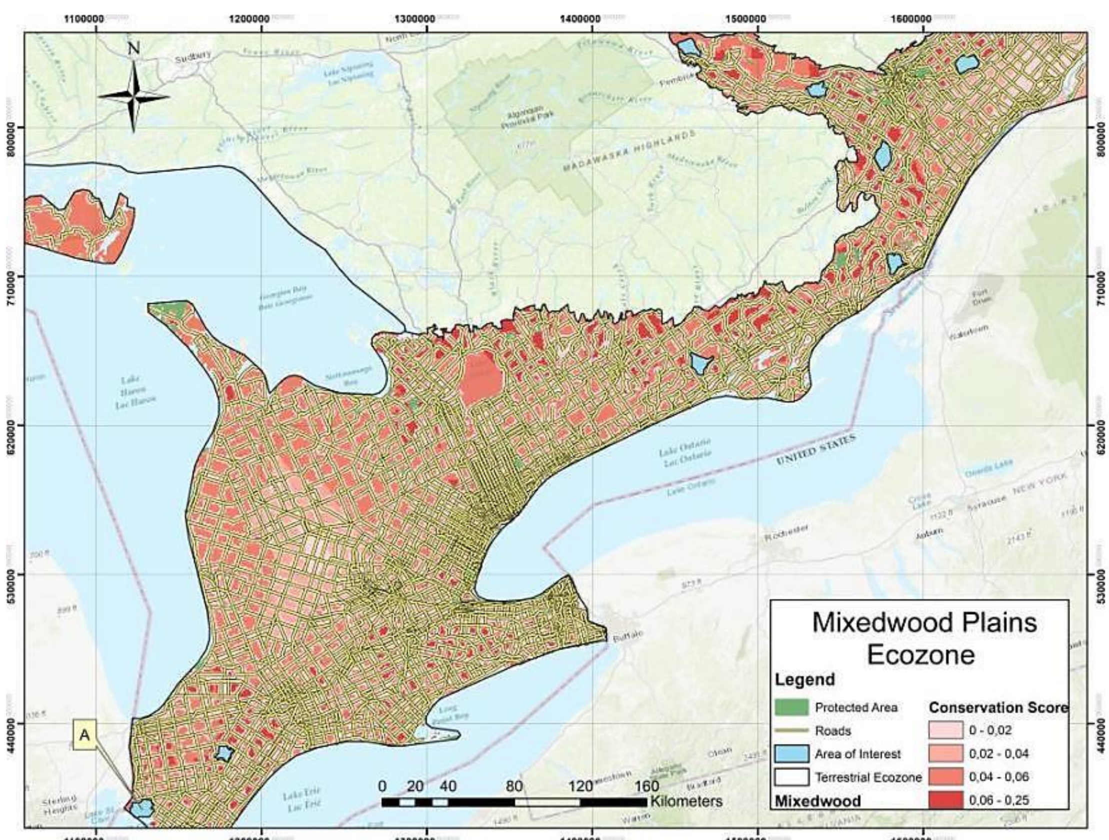
Six (6) areas of interest are found in the prairies ecozone (see in blue, figure 6). The AOIs are found in southern Saskatchewan and Manitoba within the South Saskatchewan and Assiniboine-Red drainage basin (ETP $\bar{X}$=0.37 m^3/m^2) and have a mean size of 925 km^2. Areas of interest are all found less than 20 km away from existing protected areas and cover 25 % to 49 % of CH. All AOIs are detailed (see table 10) and those with the highest final score are identified as potential protected or conserved area and labelled from A to F on figure 6. In the case of the prairies, all AOIs have the same final score. This will be reviewed further in the discussion.

Table 10: Final score for prairies AOI

Name	Size (km^2)	Ecozone	Road	Migration	SAR	ETP	Area	Final
A	**310**	**1**	**1**	**1**	**0.2**	**0.5**	**0.2**	**0.02**
B	**362**	**1**	**1**	**1**	**0.2**	**0.5**	**0.2**	**0.02**
C	**663**	**1**	**1**	**1**	**0.2**	**0.5**	**0.2**	**0.02**
D	**1080**	**1**	**1**	**1**	**0.2**	**0.5**	**0.2**	**0.02**
E	**1136**	**1**	**1**	**1**	**0.2**	**0.5**	**0.2**	**0.02**
F	**2000**	**1**	**1**	**1**	**0.2**	**0.5**	**0.2**	**0.02**

Mixedwood Plains

Figure 7: Mixedwood plains ecozone conservation score



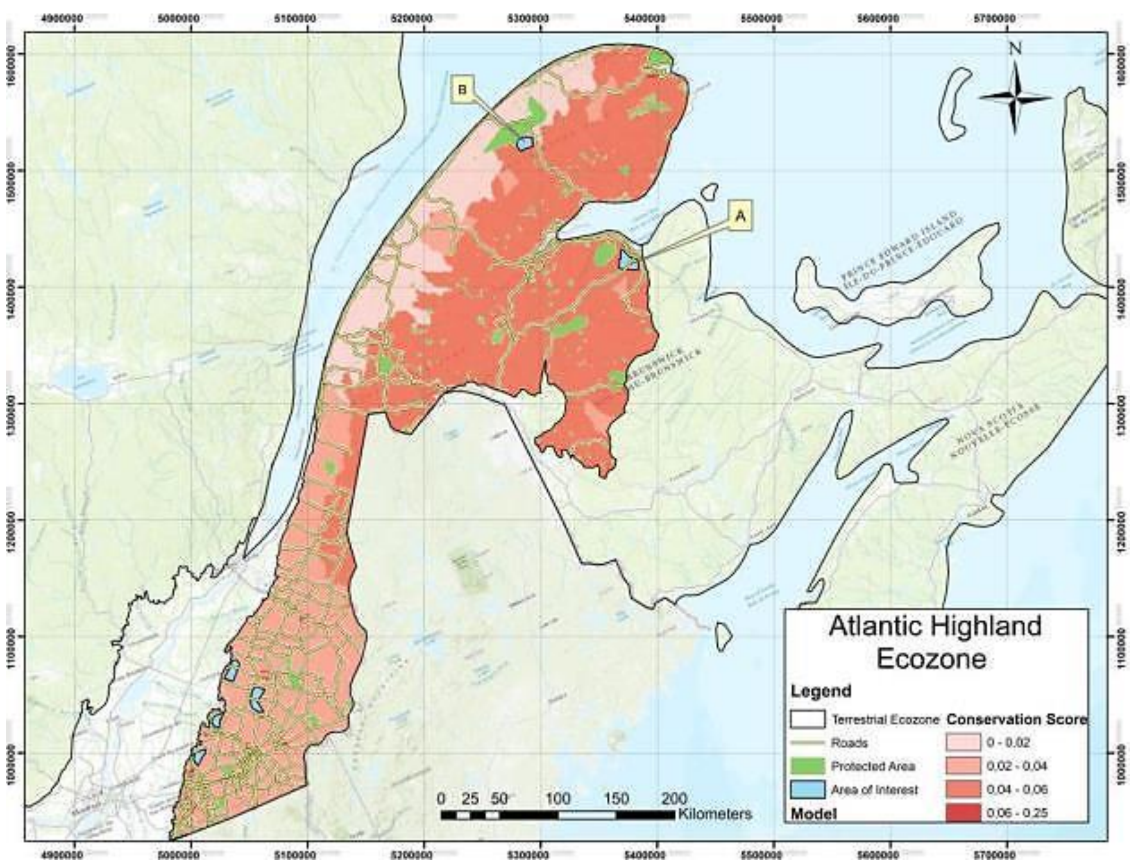
Eight (8) areas of interest are found in the mixedwood plains ecozone (see in blue, figure 7). The AOIs are found southern Quebec and Ontario in heavily urbanized landscapes within the Ottawa and Great Lakes drainage basin (ETP $\bar{X}$=0.48 m^3/m^2) and have a mean size of 92 km^2. Mean distance to existing protected areas is less than 20 km and AOIs cover 50 % of CH. All AOI are detailed (see table 11) and the one with the highest final score is identified as potential protected or conserved area and labelled A on figure 7.

Table 11: Final score for Mixedwood plains AOI

Name	Size (km^2)	Ecozone	Road	Migration	SAR	ETP	Area	Final
A	**118**	**1**	**1**	**1**	**0.3**	**0.5**	**0.2**	**0.03**
B	62	1	1	0.9	0.3	0.5	0.2	0.027
C	76	1	1	1	0.3	0.4	0.2	0.024
D	114	1	1	1	0.3	0.4	0.2	0.024
E	82	1	1	1	0.2	0.5	0.2	0.02
F	95	1	1	1	0.2	0.5	0.2	0.02
G	89	1	1	1	0.2	0.4	0.2	0.016
H	105	1	1	1	0.2	0.4	0.2	0.016

Atlantic Highland

Figure 8: Atlantic highland ecozone conservation score



Six (6) areas of interest are found in the Atlantic highland ecozone (see in blue, figure 8). The AOIs are south of the Saint-Laurence River in Northern and Southern Gaspésie and New Brunswick. They are found in the Gaspé and Maritime Coastal drainage basin (ETP $\bar{X}$=0.37 m^3/m^2) and have a mean size of 122 km^2. Areas of interest are all found less than 20 km away from existing protected areas and AOIs cover 50 % to 74 % of CH. All AOIs are detailed (see table 12) and those with the highest final score are identified as potential protected or conserved area and labelled A & B on figure 8.

Table 12: Final score for Atlantic highlands AOI

Name	Size (km^2)	Ecozone	Road	Migration	SAR	ETP	Size	Final
A	**191**	**1**	**1**	**1**	**0.3**	**0.4**	**0.2**	**0.024**
B	**121**	**1**	**1**	**1**	**0.3**	**0.4**	**0.2**	**0.024**
C	76	1	1	1	0.3	0.3	0.2	0.018
D	68	1	1	1	0.3	0.3	0.2	0.018
E	156	1	1	1	0.3	0.3	0.2	0.018
F	125	1	1	1	0.3	0.3	0.2	0.018

Variable relevance

A Spearman nonparametric correlation test with IBM SPSS© (α=0.01) on the model's 51 areas of interest found that final score is positively correlated with migration and number of species at risk (Table 13).

Table 13: Spearman correlation results for total areas of interest

	Migration	Size	SAR	ETP
Final Score	0,410**	0,197	0,501**	-0,175

** Correlation is significant at α=0.01. The results of this correlation are dependent on this study's scoring system. The definition of conservation potential is defined by the set of proxies chosen and their scoring. The results of this correlation can only be interpreted in the context of this study

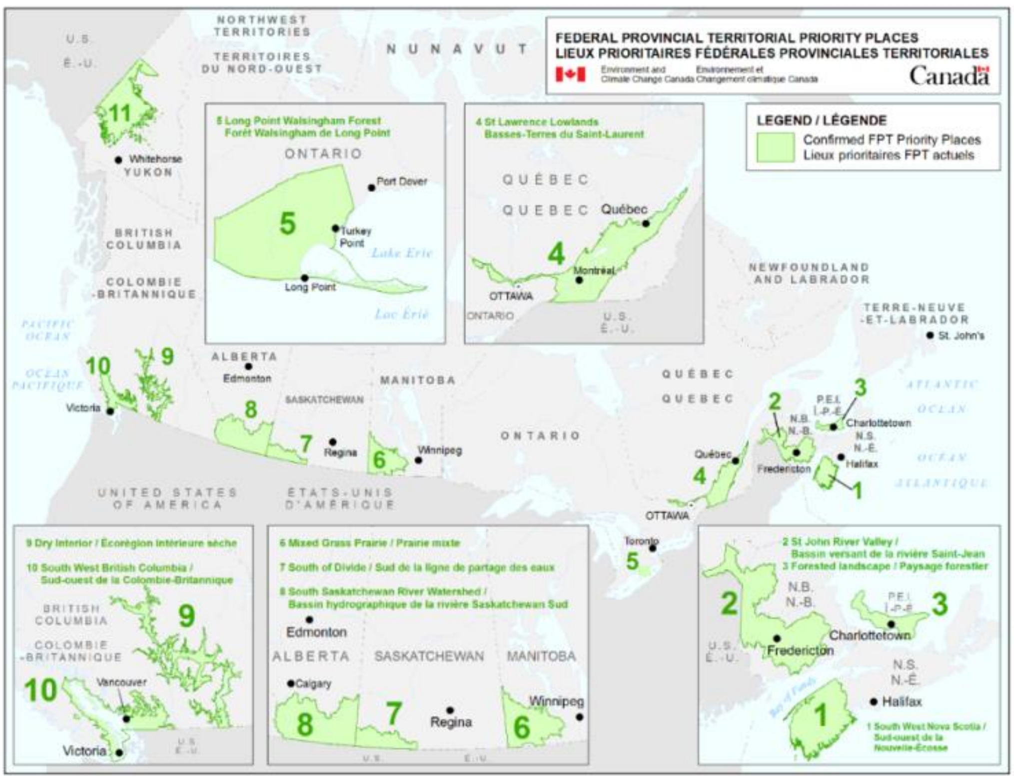
Of the model's 51 total areas of interest, 42 are found less than 20 kilometres away from existing protected areas ($\bar{X}$= 28 km). The results suggest that considerable gains in protection could be made by expanding the area of already existing protected areas. The migration proxy objective is to account for population movement in the face of current and future climate change. AOIs found close to already existing protected should allow then have better migration potential. This proxy could ignore important remote areas for biodiversity. The addition of key biodiversity areas would reduce this bias. It would also highlight potential connectivity corridors between remote KBAs and PA hotspots. Ecozones important size potentially amplifies this effect. Using a microscale ecological framework such as ecoregions or ecodistricts would widen the represented sample of habitat types.

Of the total 51 areas of interest, 17 include 100% of the ecozone SAR. This very high result is explained by the taiga shield 17 AOIs being found in the boreal caribou critical habitat. When removing taiga shield results, AOIs generally account for 25-49% of ecozone's SAR CH. In southern ecozones (prairies, mixedwood plains and Atlantic highland), mean AOI accounts for 50% of total critical habitat. The SAR proxy is to ensure that protected areas positively impact the recovery of rare or threatened species. The distribution of SAR is closely correlated with land use, leaving large areas of the country with little or no SAR (Kerr & Cihlar, 2004). Given the high inconsistencies in the number of SAR found in each of the Canadian ecozones, this proxy could have had its weight adjusted consequently to the number of SAR present in each ecozone.

Discussion

Model results

Figure 9: Environment Canada priority places (E. and C. C. Canada, 2019)



The final model share similarities with trends found in the scientific literature on protected areas in Canada. Southern Ontario, the Prairies and the Saint-Laurent Lowlands are hotspots that receive a lot of attention in conservation efforts in Canada (E. and C. C. Canada, 2016; Coristine et al., 2018; Deguise & Kerr, 2006; Woolmer et al., 2008). All three regions mentioned above are selected for analysis through the ecological representation proxy. When comparing to Coristine et al. (2018) countrywide model to inform conservation in Canada, further similarities are found in the taiga shield, high arctic and mixedwood plains ecozones. Discrepancies exist between the two models in the prairies ecozone, where Coristine et al. (2018) scores southern Saskatchewan as having low protection potential. Woolmer et al. (2008) case study on the Northern

Appalachian/Acadian ecoregions is a particularly interesting comparison. The integration of proxies such as human settlements, fragmentation through road and rails, land use change and electrical power infrastructures creates a model better integrating threats. Woolmer et al. (2008) results also highlight areas close to *Parc National de la Gaspésie* (figure 8 B) but do not see the area south of *Baie des chaleurs* (Figure 8 A) as high conservation value. Threats proxies and place-based conservation are discussed in details in a later section. Lastly, similarities with Environment and Climate Change Canada priority places (Figure 9) appear in the mixed-grass prairies and the Saint-Lawrence Lowlands (E. and C. C. Canada, 2019).

Southern Canada

In Canada, heavily urbanized areas are found along the southern transnational border. Conservation efforts have met provincial resistance due to important revenues from taxation (Dearden & Dempsey, 2004). Human pressure is driving southern resident species towards extinction. Poor protection for SAR and their important numbers in southern Canada is mostly explained by land use change (Kerr & Cihlar, 2004).

The mixedwood ecozone areas of interest are fragmented habitat patches found close to urban centers. The Lake Saint-Clair region is the highest scored area of interest (Table 11 A). Lake Saint Clair is an already recognized RAMSAR site for its great ecological potential and great migratory bird population (RAMSAR, 2014) Enlarging the already existing Lake Saint-Clair National Wildlife Area and protecting habitats on Walpole Island are options to increase ecozone protection.

The Atlantic highland ecozone areas of interest are small and fragmented. The Mont Jacques-Cartier and Mont Albert in Parc National de la Gaspésie (Table 12 B) and the Jacquet River Gorge of New Brunswick (Table 12 A) are the ecozone's highest scored areas. An isolated population of caribou found on the high peaks of the Chic-Choc in Gaspésie increases the area's potential. This region is also considered an important bird area due to the presence of rare species and the important number of breeding pairs (IBA Canada, 2016b). Increase protection could be achieved by expanding these protected areas.

The prairies ecozone, areas of interest are small and fragmented. Highest scoring areas are north of Grassland National Park (Table 10 C-D-E-F) and in the mixed-grass prairies south-west of Winnipeg (Table 10 A-B). The mixed-grass prairies are considered an IBA due to the presence of rare prairie birds at the northern part of their range (IBA Canada, 2016c). Creation of new protected or conserved areas in these isolated patches of un-fragmented prairies would increase protection in the ecozone.

Northern Canada

In the northern parts of the country, the remote wilderness allows for untouched patches of habitat to persist. Few SARs are found in the high arctic and taiga shield ecozones. Large protected areas are scattered leaving inadequate relative protection. Habitat fragmentation due to roads is rare in the taiga shield and non-existent in the high arctic.

Taiga shield's highest scoring areas are located in the eastern part of the ecozone (Quebec and Labrador) while the western part (Manitoba, Nunavut, Northwest Territories and Alberta) scores lower. The highest scoring areas (table 9 A-B) are in the boreal caribou critical habitat south of Churchill Falls and Happy Valley-Goose Bay. A southward increase of Mealy Mountains National Park or a new protected or conserved area in section B would increase protection in the ecozone. The taiga shield only SAR is the wide-ranging boreal caribou (*Ranfiger Tarandus)* (E. and C. C. Canada, 2011a). All AOIs integrate the caribou's critical habitat, increasing their final score.

The high arctic highest scoring areas are found on Baffin Island (Table 8 A-B) and around Ukkusiksalik National Park (Table 8 C-D). The area close to Baffin Island's Dewey Soper Migratory Bird Sanctuary (A) is both an IBA and a RAMSAR site due the fact that it houses the world's biggest goose colony in salt marshes (IBA Canada, 2016a; RAMSAR, 2014) Expansion of the Ukkusiksalik National Park or creation of new protected areas around Dewey Soper Migratory Bird Sanctuary would increase protection. The high arctic only SAR nests on remote cliffs above the ice sheets of Ellesmere and Devon islands (E. and C. C. Canada, 2011b). All AOIs in the ecozone have failed to include the ivory gull (*Pagophila eburnean*) critical habitat due to such habitat being excluded by the model.

Given the Canadian contrast in land use, unstable SAR numbers and overall levels of threats to biodiversity in the model's five ecozones, chosen proxies were not as relevant as intended. A threat-based approach would have yielded more significant results.

Place-based vs. threat based

The results of the study show that quantity, size, and the final score of AOIs vary greatly among ecozones. Southern landscapes are characterized by small protected area and high numbers of species at risk. In contrast, northern landscapes are characterized by large protected areas and low numbers of species at risk. Road fragmentation intensity is pronounced in southern ecozones where large and intact patches of areas do not exist outside of PA. Size of AOIs also greatly varies, negatively affecting the scoring of all southern ecozones. The proxies scoring are not well adapted to the diversity of habitats found in the five ecozones studied. Adjustments to ecological characteristic and major biodiversity threats would balance the model.

While AOIs are found in all five ecozones studied, proxy scoring varies little in southern Canada. All prairies AOIs receive the same final score, questioning the applicability of the model. Given the landscape reality of southern Alberta, Saskatchewan and Manitoba, creating reserves over 2 700 km^2 is unlikely. Road fragmentation is also a limiting factor. A holistic approach tolerating some fragmentation is needed for such landscapes to retain value. Even though studies show the negative effect of roads on biodiversity, mitigation measures exist allowing for movement in fragmented landscapes (Lesbarrères & Fahrig, 2012; Lesmerises et al., 2012; Madadi et al., 2017; Rivera-Ortíz et al., 2015; Trombulak & Frissell, 2000).

The AOIs size ranking is a problematic issue for landscapes where large areas are impossible or difficult to secure for conservation objectives. A criterion considering rare or important biodiversity areas would be beneficial instead of declaring size as entirely limiting conservation. Smaller reserves might not be as beneficial to large mammals but biodiversity as a whole needs to be conserved. The scoring chosen for size lowers dramatically the final score of smaller areas. The model is very broad and does not include threats such as agriculture, urbanization, and oil and gas exploitation. Proxies adjusted to existing threats implemented on a micro-scale would vouch for biodiversity adaptation or threat avoidance and allow a more comprehensible scoring.

Place-based conservation would benefit from threat-based measures. A mixed model would be appropriate for landscapes where population and threats are not evenly distributed, vary in intensity, impact and area of effect. In high threat landscapes, appropriate criteria would include key biodiversity area, number of species at risk, and human impact index. Place-based criteria such as average evapotranspiration and land use type can serve as base layers. Remote and wild areas criteria should include rare habitats, species occurrence and average size.

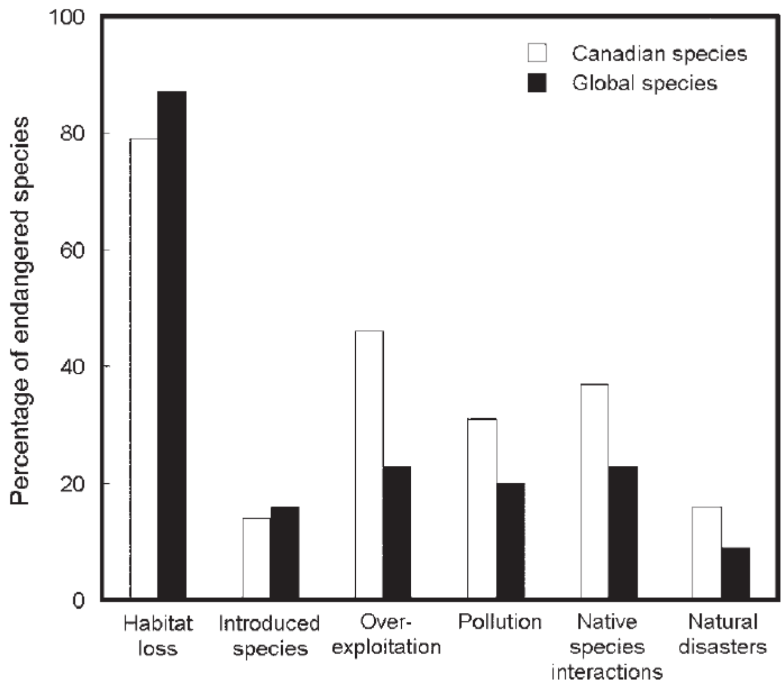
The model's two threat proxies (size and migration) are applied evenly on all five ecozones. Size ranking should be adjusted through research focused on similar landscapes. The ranking for migration should be substantiated with measures of connectivity suitable to each ecozone landscape. Moreover, fragmentation should be classified as threat-related and ranked accordingly. The measure of road influence on wildlife would benefit from the further classification of vehicle traffic and seasonal use. My results prove that discounting threats has negative consequences on the applicability of conservation frameworks.

Literature offers guidance on including threat in conservation frameworks for Canada and globally. Integrated approaches focused on local and global threats can identify areas where efforts yield conclusive results (Bonebrake et al., 2019). Acknowledging threats cumulative effects is important towards understanding how to efficiently focus conservation resources (Ibid, 2019). Venter et al. (2006) looked into threats affecting Canadian species. Upon comparing global and national threats (figure 10), habitat loss, over-exploitation and species interactions are identified as significant causes of species endangerment.

This model ranking of SAR is based on Gerber (2016) argument that resources should not always be consistent with species threat level. SAR triage approaches are proposed as a solution to resource allocation (Gerber, 2016; Martin et al., 2018; Schneider et al., 2010; Wilson, Joseph, Moore, & Possingham, 2011). Martin et al. (2018) offer guidance on prioritizing investments in SAR recovery. The study classifies chances of recovery for 13 SAR listed under the Species at Risk Act in southern Saskatchewan. The study finds that not all species can be recovered with limited funding. Management techniques individualized to each threat are analyzed and ranked by feasibility and chances of success.

Identifying the origins of biodiversity threats is of high importance. Venter at al. (2006) study reviews the origin of each threat, identifying urbanization, agriculture, resources extraction and human infrastructures as proxies of habitat loss. The study finds overexploitation to be a consequence of unsustainable levels of harvests. Species interactions are found to be caused by an increase in predation and pathogens (Ibid, 2006). Identifying and applying proxies for each threat improves the applicability of conservation frameworks (Bonebrake et al., 2019). Understanding what consideration threat proxies should receive in spatial conservation models remains sensitive and should be studied further (Tulloch et al., 2015).

Figure 10: Biodiversity threats nationally and globally (Venter et al., 2006)



The results of my study prioritize areas of interest within each ecozone. To prioritize areas at a national scale, more information needs to be considered. A cost-benefit analysis can classify conservation priorities with available information on threats origin and mitigation costs. Studies such as Martin et al. (2018) classifying sites found through systematic conservation would be beneficial. Each area of interest should have their ecosystem services biodiversity potential and total return on investments compared before deciding which one to secure. Investments in protected areas need to ensure positive results for biodiversity and ecosystem services.

Limitations

The results present limitations due to the coarseness of the data processed into the final model. Species at risk critical habitats are uploaded by Environment and Climate Change Canada as point data generalized using a 10km x 10km national grid (E. and C. C. Canada, 2015). The transformation from point data to features within ArcGIS© could have altered the spatial quality of critical habitats. Average evapotranspiration is uploaded from

Statistics Canada for drainage basins (Statistics Canada, 2017). The important areas covered by drainage basins might not reflect local variations of ETP. Additionally, the road network has been used at its more general scale. Further classification of roads could have identified very low usage trails or winter road for exclusion from the model.

The modest number of proxy selected can also be considered as limiting the result's quality. As explained above, the lack of threat-adjusted proxy impacted some of the study's results. Including proxies on land use, habitat fragmentation and rare and remote habitat could have improved the quality of areas of interest. Adjusting proxy classification in high-threat ecozones would have increased the range of scores granted to AOIs.

Given the use of publically available data found on web portals, geospatial quality of data could not be assessed. Moreover, certain data had not been updated in the last 5 years which in certain cases have skewed the model towards areas that may have transformed since.

The ranking of this model proxy is also an important limitation of the study. The study's definition of conservation potential depends on chosen proxies and could differ from other similar studies. The scoring choices for SAR and ETP proxies are arbitrary and could miss represent the impact of local and national variations. Given important national ETP variations, scoring was instead based on relative ETP by ecozone. The number of classes and their corresponding ranking considers the relationship between ETP and biodiversity as linear. Scoring based on regional variations of ETP unique to ecozone could have lowered the bias in weight distribution. The national variation in the number of SAR was also very important. As the same methodology was applied to both SAR and ETP, limitations apply to both proxies. Scorings chosen for SAR and ETP are meant to represent regional and not national variations.

Distribution of weight between the three layers further limits the results. The model is skewed towards the physical characteristics of the landscape. The SAR and ETP scoring weight is half that of other proxies. This decision is meant to support the objective of a place-based approach to conservation. Discounting the role of species at risk in the decision process for new protected areas is meant to support this objective.

Conclusion

This study's objective of a replicable place-based approach yielded mixed results. Spatially defined areas with protection potential were found in the five ecozones selected for analysis. Results hold up when compared to other conservation studies in Canada (Coristine et al., 2018; Dearden & Dempsey, 2004; Deguise & Kerr, 2006; Kerr & Cihlar, 2004) or governmental conservation efforts (E. and C. C. Canada, 2016).

The model results are skewed towards northern ecozone by virtue of their potential for large and intact patches of habitat. The bias could be removed by choosing a finer level of ecological representation (ecoregions, ecodistrics) and including key biodiversity areas. This would also counterbalance the migration proxy unfavourable effect of disregarding remote but possibly important areas for biodiversity. Different criteria adjusted to threat levels should also be part of the model instead of applying a singular set in different landscapes.

Incorporating economic data such as land value or title ownership for southern Canada would select areas where conservation efforts have chances of yielding results. The reality of land ownership and subsurface resource exploitation should not be overseen for moving from knowledge to action. Recent reports from the UN (Brondizio, Settele, Diaz, & Ngo, 2019) on global biodiversity loss and the increasing number of species at risk prove that protected areas are needed more than ever.

When possible, already existing PA could expand through adjacent land securement and procurement. In altered landscapes where protected areas cannot be implemented, mitigation measures for impacts of fragmentation and protection mechanism on private lands should be identified as priorities. The study's results show that protected areas cannot ensure SAR recovery is southern Canada. Habitat alteration is widespread and remaining patches of habitat do not have sufficient size to allow population sustainability. Identifying effective and affordable mitigation measures to major biodiversity threats should be a priority in southern Canada. Researching a SAR classification method unique to Canada based on chances of recovery would further inform emerging triage approaches. Following comprehensive reviews, the provincial and federal governments should apply protection measures (e.g. Species at Risk Act Emergency Order) overcoming private rights to protect species with good recovery potential. More research is needed to understand how to optimize return on investments for SAR recovery.

As this study's results illustrate, place-based approaches cannot yield significant results when ignoring the huge impact humans have on the landscape. Most of the recommendations found in the literature for protection only apply to relatively untouched landscapes. Future conservation efforts need to be tempered with economic and social data to better represent the reality faced by most governing authorities. The Canadian boreal forest is one of the last opportunities for large scale protected areas (Sanderson et al., 2002). While we might have a change nationally to establish reserves where natural assemblages remain relatively intact, the global reality is far from ours.

Intensifying research on the feasibility of SAR recovery and better protection against different threats would greatly complement conservation models. Human populations are now turning towards climate change resilience in the face of irreversible atmospheric concentrations of greenhouse gases. Perhaps it is time to come to term with the fact habitats are altered to a point where thinking of conservation of natural landscape is somewhat utopian.

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